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SERPENTINITES AND ASSOCIATED ROCK TYPES NEAR HOPEDALE, NUNATSIAVUT: POTENTIAL FOR ARTISANAL CARVING-STONE RESOURCES

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ABSTRACT

The carving of stone is a traditional activity in Nunatsiavut, with thousands of years of history, and it continues to contribute to the economic development of communities on the north coast of Labrador. Although modern carvers use a wide variety of materials and employ power tools, soft, altered ultramafic rocks (typically called 'soapstone', although technically serpentinite) remain the medium of choice. Serpentinite and true soapstone occur on a small scale in the Archean Nain Province, notably around Hopedale, and have been exploited on a small scale by local artists. Previous investigations suggested that larger scale extraction of carving stone might be possible at Tooktoosner Bay, very close to Hopedale, and at Adlatok Bay, located some 35 km south of Hopedale. This report discusses the Tooktoosner Bay area.

At Tooktoonsner Bay, elongated zones of variably altered ultramafic rocks, up to 1 km in strike length, are surrounded by complex quartzofeldspathic orthogneisses, and are spatially associated with unusual metasedimentary (?) rocks rich in quartz and diopside. The ultramafic rocks range from relatively fresh harzburgite with preserved igneous textures to pervasively altered serpentinite that retains only vestiges of primary minerals. Some distinctive bright-green-weathering serpentinite outcrops along the shoreline have long provided small amounts of carving stone, obtained mostly from loose material. Mapping of inland areas close to these occurrences defined a more extensive zone of closely similar material, with a strike length of about 200 m. These accessible outcrops are a few metres above sea level, and so could support larger scale extraction of stone. The total resource of such material is estimated at around 30 000 m^3, not accounting for waste, and this site fits the definition of a 'regional supplier' as defined in Nunavut. Four other zones of serpentinized ultramafic rocks were identified within 1 km of this site, and the estimated resources at two of these are of similar magnitude. However, the character of stone at these other sites is not as well established as it is for the principal site, and there are indications that the materials are less pervasively altered and more variable in hardness, which may affect suitability for carving. More field research is required in all these areas to refine initial resource estimates, to evaluate the variability and suitability of material for carving purposes, and to establish the feasibility of larger scale exploitation. There are also interesting scientific research problems to consider.

INTRODUCTION

PROJECT OVERVIEW

This article summarizes the geology of a small area around Tooktoosner Bay, approximately 3 km south of Hopedale, Labrador (Figure 1), with emphasis on altered ultramafic rocks and associated rock types. This area is close to Hopedale and easily accessible, and has traditionally provided loose 'soapstone' material used by local carvers. The term 'soapstone' is commonly used on the Labrador coast for any soft, altered ultramafic rock, although most do not meet the strict definitions for soapstone (*i.e.*, being composed largely of the magnesium silicate mineral talc).

The article is based upon two small-scale field projects that were completed under contract to Nunatsiavut, and discussed in unpublished reports (Kerr, 2015; Squires *et al.*, 2016). Related laboratory work included a student project at Mount Royal University in Calgary to investigate the mineralogy and petrology of selected samples, and geochemical analysis of selected samples at the Geological Survey. Petrological and geochemical studies are incomplete, and these aspects are discussed only briefly; the main focus of this article is on the field relationships and the identification of sites from which carving stone might be extracted on a larger scale. However, the scientific aspects of these Archean ultramafic rocks remain of much interest in the context of early Earth evolution, and the nature of serpentinization processes.

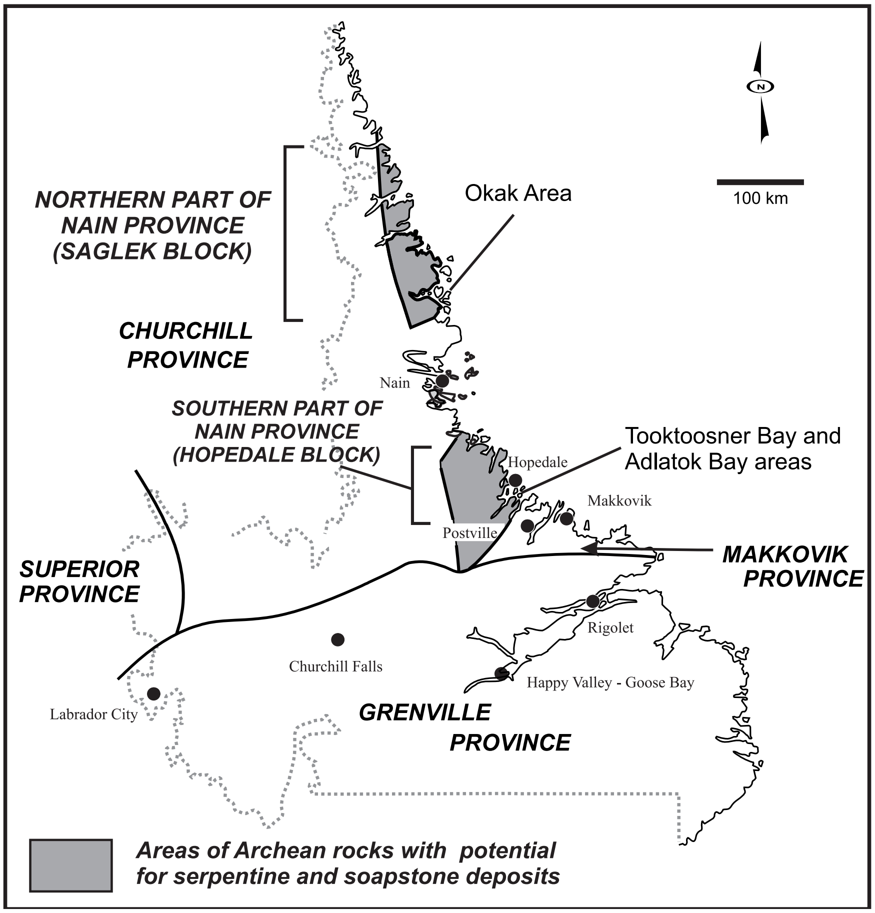

Figure 1. *Location map showing the extent of Archean rocks on the north coast of Labrador. The study area is located immediately south of the community of Hopedale.*

PREVIOUS INVESTIGATIONS AND RELATED WORK

The most recent regional geological mapping in the Hopedale area was completed by the Geological Survey of Canada (Ermanovics, 1993). This work described the ultramafic rocks at Tooktoosner Bay, but did not evaluate their carving-stone potential. Meyer and Montague (1993, 1994) completed a reconnaissance survey of carving-stone localities in the Okak and Hopedale areas (Figures 1 and 2). The Hopedale area has the largest collection of serpentinite localities close to any Nunatsiavut community, so it is the natural place to begin further evaluation of this potential.

Ten sites near Hopedale were discussed by Meyer and Montague (1994) including Tooktoosner Bay (Figure 2). These sites represent more than one geological unit as designated by Ermanovics (1993), but most are assigned to the Weekes amphibolite, which locally includes metamorphic rocks of ultramafic composition as well as mafic amphibolites. One site, located at Adlatok Bay (Figure 2), is assigned to the younger Florence Lake group, which also contains serpentinized ultramafic rocks. Serpentinized ultramafic rocks are also widespread within the Hunt River group, (which is considered equivalent to the Weekes amphibolite) but most of these localities are inland and difficult to access (Figure 2). Serpentinite sites located in coastal areas are of most interest, because year-round access is relatively easy.

Meyer and Montague (1994) highlighted two sites as having particular potential. These are located at Tooktoosner Bay, just south of Hopedale, and at Adlatok Bay (Figure 2). At Tooktoosner Bay, they identified ‘several small deposits, up to 25 by 15 m, of light-green weathering serpentinite’, and commented further on the consistent colour of this material and its suitability for fine polishing. They recommended further detailed investigation to assess resource potential and find additional sites. Most other sites are located north of Hopedale (Figure 2) and include one where there is evidence of ancient quarrying in the form of lamp preforms. This site on Semiak Island (also known as Woody Island) and sites in the area of Kangiluasuakoluk Tagani (also known as Fred’s Bay) are small but were considered to merit limited investigation. In the Adlatok Bay area, Meyer and Montague (1994) described high-quality soft serpentinite and true soapstone in an area from which material has long been removed on a small scale. They suggested further detailed investigation to establish the nature and extent of such resources. They stated that ‘this site may be the best location to begin small-scale quarrying of soapstone in the Hopedale area’.

The area around Tooktoosner Bay was explored by British Newfoundland Exploration Ltd. (Brinex) in the 1950s to investigate chrome-bearing garnet (uvarovite) reported from an unusual metamorphic rock rich in quartz and diopside (Grimley, 1959). Interpretation of this work is difficult, because the sketch map of localities and units is missing from the digital archived file. The garnets were considered too small to have any gem potential, and the site was considered too limited to have potential for abrasive materials. However, Grimley (1959) identified minor ‘limestone’ and also commented on ‘fibrous serpentinite resulting from the alteration of basic and ultrabasic rocks occurring as well-jointed masses near the shoreline.' The garnet showing presently listed at Tooktoosner Bay (MODS file number 13O/08/Gnt001) is based entirely on the report of Grimley (1959), but the exact location of their interest remains uncertain.

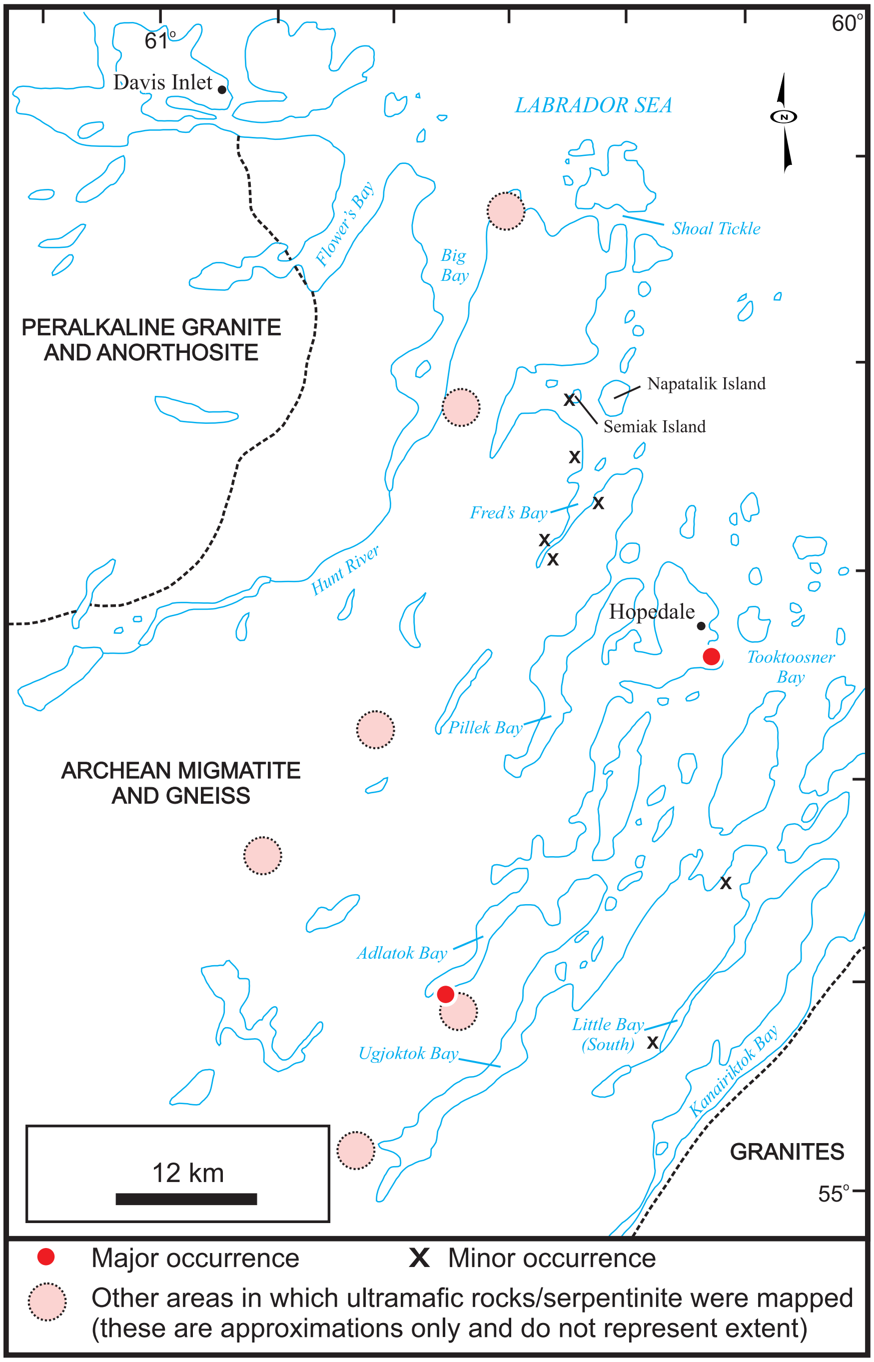

Figure 2. *Serpentinite and 'soapstone' localities in the area around Hopedale, and areas of serpentinized ultramafic rocks noted on the regional maps of Ermanovics (1993). The important localities at Tooktoosner Bay and Adlatok Bay are highlighted. Base map derived from Meyer and Montague (1994) with modifications.*

Serpentinite and 'soapstone' occurrences in the Hopedale area were also investigated from an archeological perspective, to better understand the sources of artifacts and patterns of trade or exchange within ancient cultures (Nagle, 1984). This work included some geological investigation and attempted to fingerprint sources using rare-earth-element (REE) analyses. Results suggested that individual occurrences in the Hopedale and Okak areas could not be distinguished on the basis of their REE geochemistry.

CARVING STONE IN NORTHERN CANADA

The Inuit of northern Canada have carved stone for thousands of years, and 'soapstone' has long been their material of choice. Sites in more temperate regions (*e.g.*, at Fleur de Lys in northern Newfoundland) were also exploited for soapstone by ancient cultures. Beauregard *et al.* (2013) and Beauregard and Ell (2015) discuss the many previously exploited and undeveloped carving-stone sites across Nunavut. Two types of material traditionally provide most material for carving in Nunavut, and this generalization applies also to Labrador.

The most important carving materials are commonly termed soapstone, but many such stones are more accurately described as serpentinite, which is a pervasively altered (and sometimes metasomatized) ultramafic igneous rock. True soapstone contains abundant talc [$Mg_3Si_4O_{10}(OH)_2$], which can be scratched with a fingernail. On Moh's scale of hardness (*see* explanation below), soapstone has a hardness of less than 2, which makes it easy to carve by hand. Most serpentinites are harder than this, but many can still be scratched by copper wire (hardness of ~3.5 on Moh's scale), and most can be worked with steel tools (hardness of around 6 on Moh's scale). Softer serpentinites are thus amenable to some hand carving, but harder varieties require usage of power tools. Most Inuit carvers working today use power tools in at least early stages of their craft, so the variety of stone types that can be used has expanded to include harder materials (*see* below).

Nunavut carvers also use carbonate rocks such as limestone, dolostone or marble, which are dominated by calcite and dolomite (calcium and magnesium carbonate; 3 to 4 on Moh's scale). These are also significantly harder than soapstone, but some can be worked by hand. Carbonate rocks may also display delicate laminations and/or layering (banding) of sedimentary origin, or biogenic structures such as stromatolites. Carving stones in Nunavut that are termed 'argillites' are generally finely laminated or banded carbonate rocks. Marbles are metamorphosed carbonate rocks and generally do not retain original depositional features. They are similar in hardness to unmetamorphosed carbonate rocks, but their apparent hardness may be greater due to their crystalline nature. Carbonate rocks of Precambrian and Paleozoic age are common in Nunavut around Hudson's Bay and on some of the Arctic islands, but do not occur on the north coast of Labrador. However, some Nunatsiavut carvers do work with carbonate rocks, notably white dolostone from the Leila Wynne quarry in western Labrador. Carbonate materials are typically used to provide contrast with dark serpentinites in composite works, so local sources of suitable material in Nunatsiavut would be of interest.

PHYSICAL PROPERTIES OF STONE AND SUITABILITY FOR CARVING

Moh's scale is a simple (but nonlinear) measure of hardness that is based on index minerals. The effective hardness of most rocks is not constant but will vary on a small scale according to the minerals present and their proportions, and the strength with which individual mineral grains are held together. Thus, minor quantities of harder minerals in an otherwise soft serpentinite may not adversely affect its suitability for carving, whereas larger quantities of hard material may be deleterious. The influence of hardness on carving 'suitability' is complex (N. Noel, personal communication, 2015). Softer stones can be shaped and worked more rapidly with hand tools, but they are less durable, do not polish as well, and may not permit the introduction of fine detail. Conversely, harder stones may require power tools and/or take longer to work, but they are more durable, generally provide a higher quality polish, and can better retain fine detail. Grain size is also important, as most rocks generally cannot retain detail that is smaller in scale than average grain size.

Other aspects of stone that are not easily quantified, such as colour and texture, may strongly influence the suitability of materials, and may outweigh less favourable physical properties. Mineralogy is also important because serpentinites may contain fibrous minerals such as crysotile or tremolite–actinolite that fall under the definition of 'asbestos'. These asbestiform minerals represent a health risk to carvers, because copious amounts of dust are generated through the use of power tools.

The use of power tools in carving is now widespread in Nunavut and Nunatsiavut, and this has expanded the choice of potential raw materials. Labradorite-bearing anorthosites from the area around Nain (previously exploited also for dimension stone) have become popular with some Nunatsiavut carvers. Anorthosites have the advantage of being quartz-free, even though they are much harder than typical serpentinites. Other igneous and metamorphic rocks may also have future potential as raw materials, but at present the main interest in Nunatsiavut remains with altered ultramafic rocks.

In the final analysis, deciding if a particular stone has potential for use in carving is not a simple matter, as it does not only depend on physical properties such as hardness. A thorough assessment of the suitability of a given material can only be obtained through its experimental use by carvers, and they may not all agree in their opinions. Field work around Tooktoosner Bay was assisted by Ross Flowers and Tony Gear of Hopedale, who both have experience as carvers, and their opinions and experiences with samples were an important part of the assessment effort. Particular effort was also made to locate rock types that were familiar to local carvers from the exploitation of loose material in nearby coastal locations. This assessment was of a reconnaissance nature, and more systematic evaluation by local carvers is required for all the sites identified in this report.

SIZE CHARACTERISTICS OF VIABLE ARTISANAL STONE DEPOSITS

The most important characteristics of a potential carving-stone deposit are its colour and appearance, physical properties such as hardness, its suitability for shaping and polishing, and the maximum size of blocks that can be extracted. However, size is also important in terms of development potential, and Beauregard *et al.* (2013) defined four major categories for carving-stone deposits in Nunavut.

1. Deposits ranging from a few tonnes to hundreds of tonnes of stone are considered individual suppliers suited only for use by individual carvers or small groups of carvers. These are numerous, but limited in potential; many consist of loose material and their locations may be closely guarded secrets.

2. Deposits ranging from a few hundred tonnes to thousands of tonnes are considered community suppliers sufficient to serve the demands of small communities

on short time-scales (the communities of the Labrador coast and Nunavut are similar in populations, so this definition should apply).

3. Deposits containing several tens of thousands of tonnes are considered regional suppliers with resources sufficient to serve several nearby communities for decades.

4. Deposits containing hundreds of thousands of tonnes to a million tonnes or more are considered Nunavut-wide as their resources are sufficient to service the entire territory for many years. Given the smaller population of Nunatsiavut compared to Nunavut, the threshold size for such a deposit on the Labrador coast would be substantially less than for Nunavut.

In the context of resources, volumetric estimates (in cubic metres) are commonly employed for stone, and are used in this report. The specific gravities of typical rocks range from around 2.5 to over 3, and serpentinites are typically at the upper end of this density range. Thus, a 1000 m^3 deposit would represent approximately 3000 tonnes. Even small deposits (several tens of cubic metres) can have substantial value to artists, especially if they have unique characteristics, but larger deposits of consistent quality and character are needed to sustain this industry and allow it to expand. In both Nunavut and Nunatsiavut, artisanal carving provides an important source of income in small communities, and there is a perceived shortage of high-quality raw materials that are easily accessible. Nunavut developed an action plan about 10 years ago with the objective of defining potential sites and resolving complications linked to transportation and infrastructure (Nunavut Department of Economic Development and Transportation, 2006). Nunatsiavut has not yet developed such a strategic plan, but this study was intended to assess at least one potential deposit as a potential regional supplier. Attention was focused on Tooktoosner Bay largely because of its favourable location; the site identified by Meyer and Montague (1994) at Adlatok Bay was also visited briefly in 2016 (Squires *et al.*, 2016), but more work is still required there.

REGIONAL AND LOCAL GEOLOGY

The study area forms part of the Hopedale Block, which is the southern part of the Archean Nain Province (Figure 1). The oldest rocks in the area consist of tonalitic to granodioritic orthogneisses grouped as the Maggo gneiss. These have a complex early history that predates their stabilization around 3250 Ma (Ermanovics, 1993; James *et al.*, 2002). The oldest mafic and ultramafic rocks are known as the Hunt River group where they are regionally extensive, and as the Weekes amphibolite, where they are contained within the Maggo gneiss on a smaller scale. The age of the Hunt River group is estimated at *ca.* 3100 Ma (James *et al.*, 2002). The geochronological data that define early events (summarized by Ermanovics, 1993, and James *et al.*, 2002) are sparse and variably reliable, because many were acquired in the 1970s and 1980s.

Mafic to ultramafic volcanic rocks and less abundant sedimentary rocks of the *ca.* 3000 Ma Florence Lake group were deposited on a basement composed of the Maggo gneiss and Hunt River group. James *et al.* (2002) argue that there is no evidence of deformational events separating the formation of the Hunt River group and Florence Lake group, contrary to the view of Ermanovics (1993). The Florence Lake group forms several elongate belts south of Hopedale, and has traditionally been the focus of exploration, due to its sulphide occurrences and perceived gold potential. The Maggo gneiss and the Florence Lake group were intruded by younger tonalites and granodiorites of the Kanairiktok intrusive suite at *ca.* 2900 Ma (Ermanovics, 1993; James *et al.*, 2002), and the entire Hopedale Block was affected by later deformation and metamorphism at *ca.* 2750 Ma. Minor granitic and pegmatitic rocks of unknown age intrude all of the above units, and are variably deformed; they are presumed to be of later Archean age. Proterozoic diabase intrusions known as the Kikkertavak dykes cut all of the above units, including the youngest granites and pegmatites. These are fresh and unmetamorphosed, and are dated at 2235 ± 2 Ma (Cadman *et al.*, 1993). Mesoproterozoic diabase intrusions known as the Harp dykes also occur in the Hopedale Block, and are dated at *ca.* 1273 ± 1 Ma (Cadman *et al.*, 1993). These are not as widespread as the Kikkertavak dykes, and no examples are known in the study area.

The Hunt River group, Florence Lake group and the Weekes amphibolite all include ultramafic rocks that are locally serpentinized. The most extensive areas of such ultramafic rocks are inland but numerous smaller zones occur around Hopedale, with strike lengths ranging from a few metres to over 1 km. Most of these smaller bodies were assigned by Ermanovics (1993) to the Weekes amphibolite, although the criteria for such assignment are not always clear.

GEOLOGY OF THE TOOKTOOSNER BAY AREA

The Tooktoosner Bay area contains most of the components summarized above, although the exact assignment of the ultramafic rocks remains open to discussion (*see* below). The most abundant outcrops are typical Maggo gneiss. All small amphibolitic and other mafic–ultramafic pods scattered within the Maggo gneiss are here assigned to the Weekes amphibolite, following Ermanovics (1993). However, the more extensive ultramafic rocks discussed in this report could instead be broadly equivalent to the

Florence Lake group. In this report, the informal term "Tooktoosner ultramafic suite" is used to distinguish them from the numerous small bodies. In several areas, the Tooktoosner ultramafic suite is spatially associated with unusual diopside and/or quartz-rich rocks of uncertain origin. Kerr (2015) speculated that they might be calc-silicate rock types of 'metasomatic' origin related to the ultramafic intrusions, but it is also possible that they are metasedimentary rocks, and they are here placed in a separate unit.

Weakly foliated to massive granitoid rocks including true granites, fine-grained aplite and coarse-grained pegmatite, are common everywhere around Tooktoosner Bay, and these intrude both the Maggo gneiss and the Tooktoosner ultramafic suite. The pattern of intrusion is complex, and there are several different generations of granitic rocks, so resolving all contact details is very difficult. Many outcrops consist of more-or-less equal mixtures of older banded gneiss and younger massive granite, and cannot easily be assigned to a single unit. The granitic rocks are collectively correlated with the Kanairiktok intrusive suite, as they truncate banding in the Maggo gneiss and cut its contacts with the ultramafic rocks. However, the ultramafic rocks generally contain lesser amounts of 'invasive' granite than the surrounding banded gneisses. This suggests that some of the granitic rocks that disrupt the Maggo gneiss might be older than the Tooktoosner ultramafic suite, but this cannot be proved, as it could also reflect rheological differences between the Maggo gneiss and serpentinized ultramafic rocks. Undeformed diabase dykes are common on all scales and cut all other rock types; these are assigned to the Kikkertavak dykes.

The geology of the Tooktoosner Bay area is summarized in Figure 3. The Tooktoosner ultramafic suite is relatively easy to delineate, as are the Kikkertavak dykes, but most of the latter are too narrow to represent at scale and are not shown on the map. The Maggo gneiss and the variable plutonic rocks equated to the Kanairiktok intrusive suite are a different matter, as both are present in similar amounts in many outcrops. Where more than one unit designation is given in Figure 3, the first-listed rock type is considered to be dominant.

ROCK TYPES AND RELATIONSHIPS

Unit 1: Maggo Gneiss (Including Weekes Amphibolite Remnants)

The Maggo gneiss (Unit 1a) is the most abundant rock type in the study area. Typical outcrops are layered grey, white and pink granitoid gneiss. Most outcrops also contain dark layers of mafic gneiss, which likely represent rotated and sheared diabase dykes. Local migmatization adds an additional layer of complexity to many outcrops. The Weekes amphibolite (Unit 1b) consists of thin amphibolite and pyroxenite layers, commonly with compositional layering, typically strongly recrystallized. These zones can generally be traced for only a few tens of metres, and the more extensive areas of Weekes amphibolite indicated on the maps of Ermanovics (1993) to the south of Tooktoosner Bay actually consist of innumerable thin mafic layers within the granitoid gneiss.

Unit 2: Tooktoosner Ultramafic Suite

This unit includes variably serpentinized ultramafic rocks (Unit 2a, 2b) that form relatively continuous bodies over hundreds of metres, and which show much less evidence of structural and migmatitic disruption than the Weekes amphibolite (Unit 1b).

The Tooktoosner ultramafic suite is present in several discrete areas (Figure 3). From north to south, the four main coastal areas are referred to as the Northern Zone, the Twin Points Zone, the Soapstone Cove Zone and the Dark Island Zone. A smaller area located a few hundred metres inland is termed the Gully Zone. There are no formal published names from which to draw names for localities in this area, although many features likely have local Inuktitut designations; the informal names used in the field are retained for reference in this report. The Soapstone Cove Zone extends for about 600 m, opposite and south of Dark Island; it may originally have been continuous with the Twin Points Zone to the north, as the two are mostly by younger granitic rocks (Figure 3). Similarly, the Dark Island Zone may be an offshore extension of the Soapstone Cove Zone, but it is convenient to treat it separately. The Northern Zone consists of three small areas of ultramafic rocks surrounded by Maggo gneiss, and the Gully Zone is similar in size to each of these. The Twin Points and Soapstone Cove zones approximately coincide with the area of ultramafic rocks mapped by Ermanovics (1993), but the other areas were not identified by earlier mapping, or were omitted from maps due to their limited extent.

The ultramafic rocks in all areas are broadly similar, and the freshest examples (Unit 2a) are coarse-grained rocks consisting mostly of olivine and orthopyroxene (*i.e.*, harzburgite). Ermanovics (1993) described some as lherzolite, indicating that they also contain clinopyroxene, but this mineral was not identified in the field. Light-brown 'spots' and 'blotches' seen on many weathered outcrop surfaces are interpreted as variably preserved igneous orthopyroxene within a more altered olivine-rich matrix. Most outcrops display some serpentinization, and some are pervasively altered. The serpentinization process eradicates most original textures, and produces fine-grained dark material of variable hardness. Serpentinized rocks (Unit 2b) display a range of colours on weathered surfaces, from bright green to brown, or more rarely beige. They typically show smooth surfaces and well-developed glacial striae, which are indicators of relative softness and amenability to polishing. Remnants of primary orthopyroxene and possibly olivine remain locally visible, but the serpentine-group minerals are too fine grained for visual identification. Ermanovics (1993) also reports phlogopite (Mg-rich mica), tremolite–actinolite (fibrous amphiboles) and other minor minerals including spinel and magnetite, but does not mention talc. Plate 1 illustrates some typical examples of unaltered to mildly altered ultramafic rocks assigned to Unit 2a.

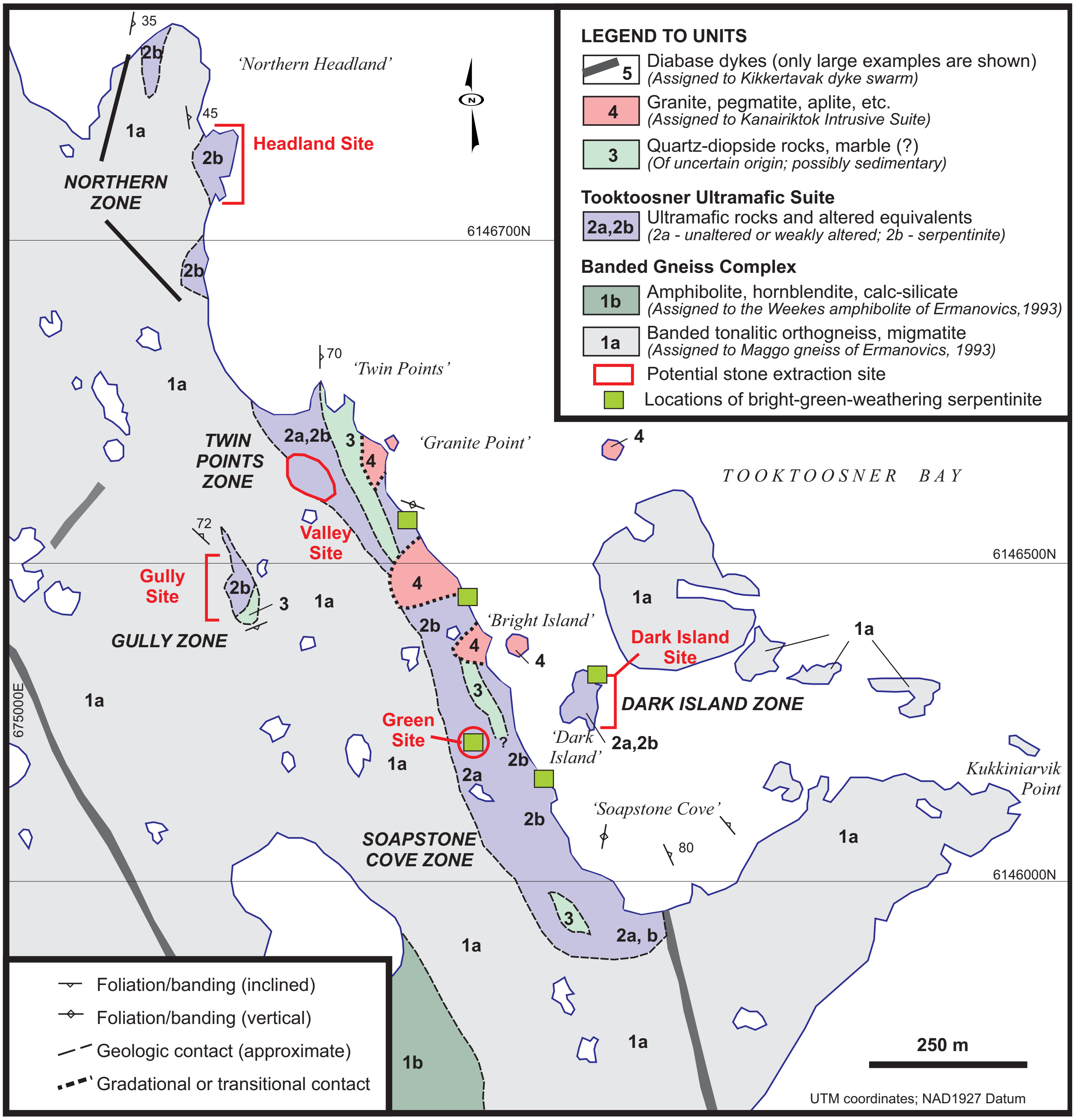

Figure 3. *Simplified geological map of the area of investigation, showing zones of altered ultramafic rocks and sites that have potential for carving-stone extraction. Modified after Kerr (2015) to incorporate more detailed investigations completed by Squires* et al. *(2016).*

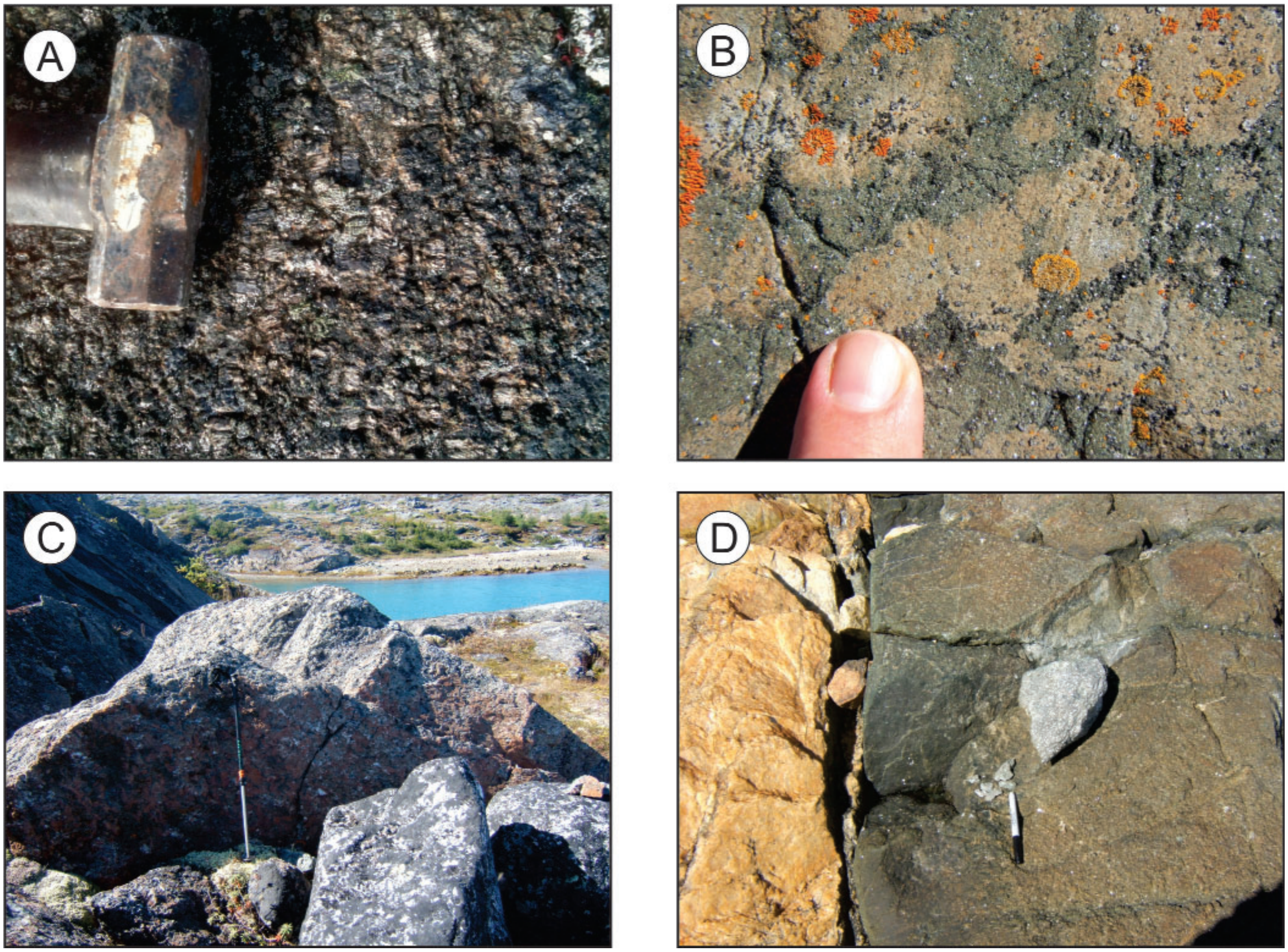

Plate 1. *Photos of relatively well-preserved ultramafic rocks around Tooktoosner Bay. A) Coarse-grained, relatively fresh ultramafic rock consisting largely of orthopyroxene, with minor olivine; B) Texture of weakly serpentinized ultramafic rock, showing large orthopyroxene masses surrounded by altered olivine; C) Massive, weakly serpentinized ultramafic rock exposed on the summit of Dark Island; D) Contact between medium-grained ultramafic rock, with mild alteration (right) and younger granitic unit (left). Broken piece shows pale-grey colour of fresh surface.*

Unit 3: Quartz- and Diopside-rich (Metasedimentary?) Rocks

Unit 3 includes unusual light-coloured, locally banded rocks that are rich in quartz, diopside and possibly other calc-silicate minerals. The origins of these rocks are uncertain, but they are spatially associated with variably altered ultramafic rocks in at least three areas.

At Twin Points (Figure 3) serpentinized ultramafic rocks are in contact with a thin, dull-grey calcite-rich unit that contains quartz stringers (presumably the 'limestone' of Grimley, 1959), which is in contact to the east with a massive to finely banded pale-green rock that is very hard and quartz-rich, and locally displays complex fold patterns. The green mineral in this rock type was identified in the field as a pyroxene (probably diopside variety), but these rocks also match the descriptions of the uvarovite-bearing unit of Grimley (1959). However, no garnet was identified in the field, and no garnet was observed in thin section (*see* later note). Similar rocks occur in the Soapstone Cove Zone, where they may be an along-strike continuation of those exposed at Twin Points, and they also occur locally in the Gully Zone (Figure 3). Plate 2 illustrates these unusual rocks at the Twin Points locality, where the ultramafic rocks to the west become markedly finer grained adjacent to their contact with the calcareous unit to the east, suggesting that they might be chilled (Squires *et al.*, 2016). This raises the possibility that the banded quartz-diopside-rich unit might represent older metasedimentary (?) country rocks, and that the intervening 'limestone' might have formed from reactions in the contact zone. However, the contact between the ultra-

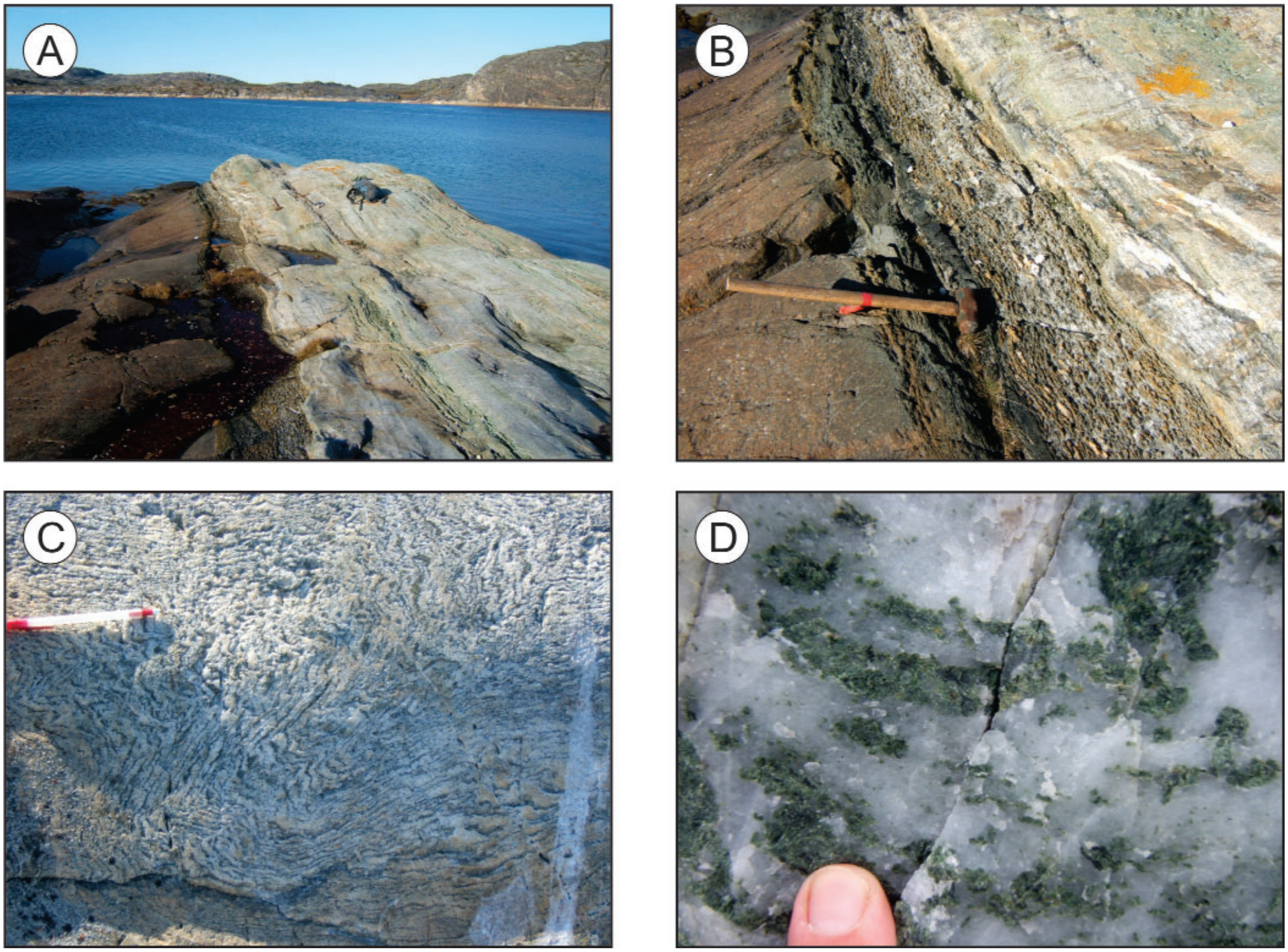

Plate 2. *Photos of possible metasedimentary rocks in the Twin Points area. A) Contact zone between serpentinite (left) and the banded quartz–diopside rock (right) at Twin Points; B) Detailed view of the contact between serpentinite (left) and the quartz–diopside rock (right) with carbonate unit developed at the contact. Note suggestion of chilling in the ultramafic rock; C) Complex folding in the quartz- and diopside-rich rock type interpreted as a metasedimentary rock; D) Green diopsidic pyroxene and quartz in the possible metasedimentary unit at Twin Points.*

mafic rocks and Unit 3 is strongly sheared, so the observed spatial relationships may not be original. Preliminary petrography indicates that Unit 3 contains little or no carbonate or calc-silicate minerals other than diopside, so it is here interpreted as metasedimentary rock, perhaps originally a calcareous sandstone, which is older than the adjacent ultramafic rocks.

As interesting as it is, Unit 3 has no potential for carving stone because it is quartz-rich and extremely hard. The dull-grey 'limestone' unit that marks its contact with the adjacent ultramafic rocks also contains many patches of quartz, and is almost as hard, despite being largely composed of calcite.

Unit 4: Granitoid Rocks (Provisionally Assigned to Kanairiktok Intrusive Suite)

Massive granitoid rocks are extremely difficult to separate from the Maggo gneiss (Unit 1) at any mapping scale, and no attempt was made to subdivide granitoid rocks or fully resolve their characteristics. Some typical rock types and relationships are illustrated in Plate 3. Granitic veins and masses cut the Tooktoosner ultramafic suite (Unit 2), and serpentinite xenoliths are locally observed within the granites. The metasedimentary (?) rocks of Unit 3 are also extensively invaded by granitoid rocks of variable composition and texture.

Unit 5: Diabase Dykes

Undeformed diabase dykes range in width from a few centimetres to tens of metres, and their contacts are clearly discordant to banding in the Maggo gneiss. Wider dykes exhibit chilled margins against these older country rocks. The dykes cut all rocks assigned to the Tooktoosner ultramafic suite, but are harder to recognize in the serpentinitic varieties, against which they show little colour contrast. The dykes also cut the metasedimentary (?) rocks of Unit 3 and the granitoid rocks of Unit 4, so they are clearly the youngest rocks in the area. Plate 4 illustrates some examples of diabase dykes and their contact relationships.

STRUCTURE

The Maggo gneiss obviously has a complex early history, and intricate fold patterns are commonly observed on an outcrop scale. On a more regional scale, the attitudes of compositional banding in the Maggo gneiss, lithological contacts between Units 1, 2 and 3, and foliations in these units are all broadly subparallel (Figure 3). Strike ranges from north-south to northwest-southeast, and planar elements generally dip steeply to the east, or are subvertical, aside from a small area in the north, where dips are gentler (35° or so). It is suspected that most of the contacts between Unit 1 (Maggo gneiss), Unit 2 (Tooktoosner ultramafic

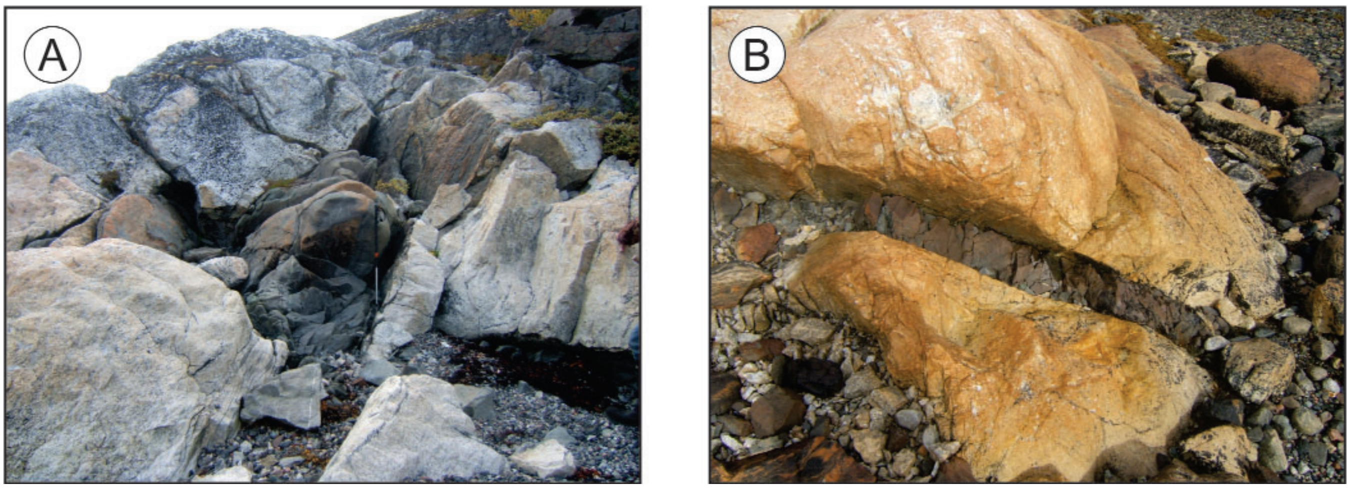

Plate 3. *Photos of late granites and contact relationships. A) Inclusion of serpentinite in massive granite (centre of photo) indicating the age relationship of these two units; B) Leucocratic quartz-rich granite sheet, cut by a diabase dyke about 10 cm in width, Twin Points area.*

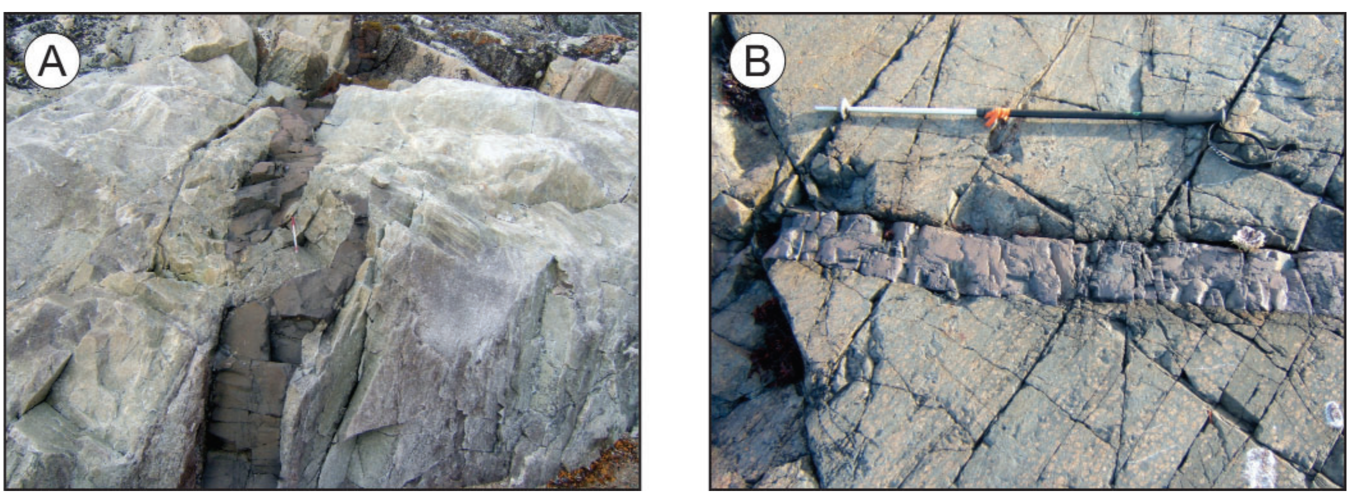

Plate 4. *Photos of diabase dykes and their contact relationships. A) Narrow diabase dyke cutting banded quartz–diopside (metasedimentary?) rocks; B) Narrow diabase dyke cutting serpentinized ultramafic rock. Note orthopyroxene 'spots' in the older rock type.*

suite) and Unit 3 (metasedimentary rocks) are tectonic, and that original intrusive relationships are rarely preserved. A possible exception is at Twin Points, where the ultramafic rocks appear to be chilled against Unit 3, but this may also be modified by deformation (*see* above). Shearing along contacts, and within the ultramafic units, may have facilitated the fluid alteration processes that led to serpentinization. The generally steep attitudes of foliations and contacts suggest that most surface outcrops will have depth continuity.

SERPENTINITE OCCURRENCES

General Information

The Tooktoosner ultramafic suite contains many localized zones of serpentinization that are of interest for carving stone. Serpentinization is most widespread in the Soapstone Cove Zone, where local carvers have retrieved loose material along the shoreline from several localities. Other coastal localities near Twin Points and on Dark Island (Figure 3) have also provided loose material, and there may well be other sites that the authors remain unaware of. Most areas of small-scale extraction correspond with a distinctive bright-green serpentinite that is dark green to black on its fresh surfaces, and the recognition of material similar to this was a primary objective of this study. Evaluation of material in the field was based to a large extent on hardness; any stone that can be scratched with copper wire, and/or abraded easily with a steel file, may have potential for carving. Relatively large coherent (unjointed) blocks also need to be available in various size ranges to permit use for larger works. The most intensely altered, softest, materials tend to have a high fracture density and occur mostly as small pieces, which limits their potential, whereas less intensely altered material is generally more massive. Important information is also provided by the quality of natural glacial polishing and the abundance of glacial striae, both of which indicate relative softness. Kerr (2015) evaluated five sites where serpentinite is extensively developed (Figure 3) and might yield substantial quantities of stone. One site in particular, known as the 'Green Site' is considered to have the highest potential for development. Squires *et al.* (2016) completed additional work to better define all these areas, and largely verified initial findings, but also recognized new complexities and identified additional resources.

Resource Estimation Methods

General estimates of the resources at a given site were obtained using a simple method. For each site, local topography was extracted from a digital elevation model obtained from high-resolution satellite imagery (marketed by Digital Globe) provided by the Geography Department at Memorial University, as part of their Sustainable Communities project with Nunatsiavut. This elevation model is considered accurate to approximately 1 m. A rectangular grid was established over each site on the satellite images, with a point spacing of 5 m. This was converted to a three-dimensional elevation model consisting of vertical columns measuring 5 by 5 m on each side. From this, the volume of material located above a given horizontal datum is easily derived. A horizontal datum of 2 m was used for all coastal sites, and a minumum datum of 5 m was used for inland sites, depending on their actual elevations. Resource estimates for coastal sites are more sensitive to inaccuracies in the elevation model. Conversions from volume to tonnage are based on an assumed specific gravity of 3. The method used for estimation is illustrated schematically in Figure 4 (after Kerr, 2015). It is important to note that these are general first-order estimates only, and take no account of waste material within the resource, which cannot presently be quantified.

Soapstone Cove Zone

In the Soapstone Cove Zone intensely altered bright-green to brown-weathering ultramafic rocks occur widely as beach debris, and form several intermittent outcrops along the shore (Figure 3). These have provided loose material

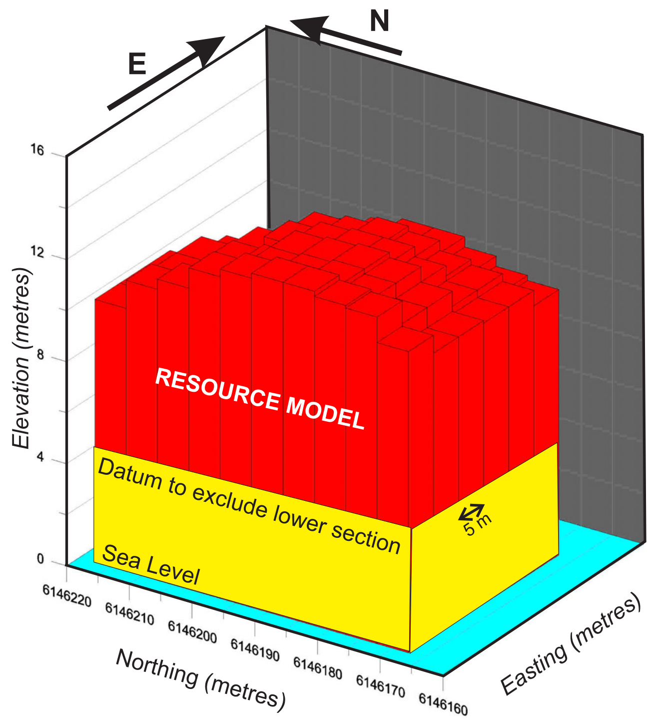

Figure 4. *Illustration of resource calculation methods, using an elevation model derived from satellite imagery to create a 3-D representation of a site using multiple columns measuring 5 m on each side. The total volume of material above sea level is calculated first, and then the volume beneath a given horizontal datum is subtracted from the total.*

used by local carvers, but the remaining resource on the shore is limited because all locations are essentially at sea level. Typical examples of serpentinized material are illustrated in Plate 5. The bright-green-weathering material has been preferentially used by carvers, but tends to occur mostly as small, fractured pieces, so wastage is very high. Note that the striking green colour is a property of the weathered surfaces only, as the fresh material is black with flecks and lines of dark green. Original igneous textures, notably orthopyroxene masses, are locally preserved, but in many areas the alteration is pervasive, and no original textures are preserved. Some outcrops also contain discrete crosscutting veins of serpentine minerals.

The greatest resource potential is in some near-shore locations where similar serpentinite occurs at slightly higher elevations (up to 20 m asl.) that would permit larger scale exploitation. The area of most interest is termed the 'Green Site'. This outcrop consists of material that is closely similar to the green-weathering material exploited on the shore, although its outward appearance is different because it has a pale-brown to beige-weathering crust. Freshly broken surfaces show that the brownish colour forms an outer rind, and that there is an inner zone of green weathering, surrounding a fresh serpentinite that is black with dark-green flecks and lines (Plate 5). This material is consistently soft, and easily scratched with copper wire, indicating that its hardness is less than 3.5 on Moh's scale. The difference in appearance between the inland and shoreline outcrops presumably indicates that the outer brownish rind is mostly removed by erosion in the high-energy beach environment. The close similarity to previously exploited material that occurs along the shoreline indicates that this material is equally suitable for carving and it was rated as 'very good' by local carvers.

The 'Green Site' is shown in greater detail in Figure 5, with satellite imagery. Kerr (2015) estimated the resources in the original outcrop at ~5500 m^3, or ~16 500 tonnes, assuming a horizontal datum of 5 m asl. This would place it in the 'community supplier' class of resource, or at the lower end of the 'regional supplier' class (Beauregard *et al.*, 2013). More detailed mapping showed that the intensity of serpentinization is more varied than originally thought, and that the western half of the outcrop retains more primary olivine and orthopyroxene, which makes it harder (Squires *et al.*, 2016). The distinction was not recognized initially because both parts show similar weathering and have soft outer surfaces. Investigation of surrounding outcrops revealed two additional areas of the soft serpentinite along strike to the north, which add significantly to the overall resource. Squires *et al.* (2016) suggested a total volume of ~14 000 m^3 (using a 5 m datum) or 18 700 m^3 (using a 3 m datum), dispersed over the three separate areas. This estimate includes only the softer material; with the harder material in the west added in, the total volume becomes over 30 000 m^3, or close to 100 000 tonnes. It is also likely that the soft serpentinite is continuous in the unexposed areas between the individual outcrops (Figure 5). Substantial expansion of the potential resource now places this site in the category of a 'regional supplier' (after Beauregard *et al.*, 2013). Samples collected along the shoreline of Soapstone Cove south of the Green Site were also rated as 'very good' by local carvers, but the available resource is small because these sites are at sea level. However, the area just inland from these outcrops has not yet been investigated in detail, so further expansion of resources is possible.

Dark Island Zone

Aside from a few granitic dykes and sheets, the island here termed 'Dark Island' is entirely composed of ultramafic rocks and serpentinite. The serpentinites are mostly found around its northern end and eastern side, and locally include bright-green, highly fractured material that resembles material from the adjacent Soapstone Cove Zone (*see* above). Partially serpentinized areas retain brownish clots of less altered orthopyroxene, and are notably harder than the typical serpentinites around Soapstone Cove. There is a wide variety of weathering colours, and several areas consist of vein-like serpentinized zones that apparently cut through less altered ultramafic rocks, but have gradational boundaries against them. Some features of local outcrops are illustrated in Plate 6. The volume of the entire island above sea level is estimated at around 12 000 m^3, but using a horizontal datum of 2 m cuts this volume in half, such that the total resource is a few thousand m^3. However, not all of this material is strongly serpentinitized, so the quantity of usable material is significantly less than this. Samples from Dark Island were not rated highly by local carvers as they were considered to be too hard, reflecting the greater preservation of original igneous minerals. However, the varied nature of the stone suggests that small quantities of material could be extracted from localized zones, even if more extensive and continuous zones are absent. More field work is required on Dark Island to identify local zones of softer material that may have distinctive colours or textures, but any large-scale extraction of material seems unlikely.

Twin Points Zone

The Twin Points Zone contains several small areas of strongly altered material along the coastal outcrops, south of Twin Points, and there is some evidence of previous extraction of material west of that locality. The resources in all these areas are limited by their location at sea level. Kerr (2015) identified a larger inland area of serpentinized ultramafic rocks at its northwestern end, which is known as the 'Valley Site' (Figure 3). This site is in many respects a 'nat-

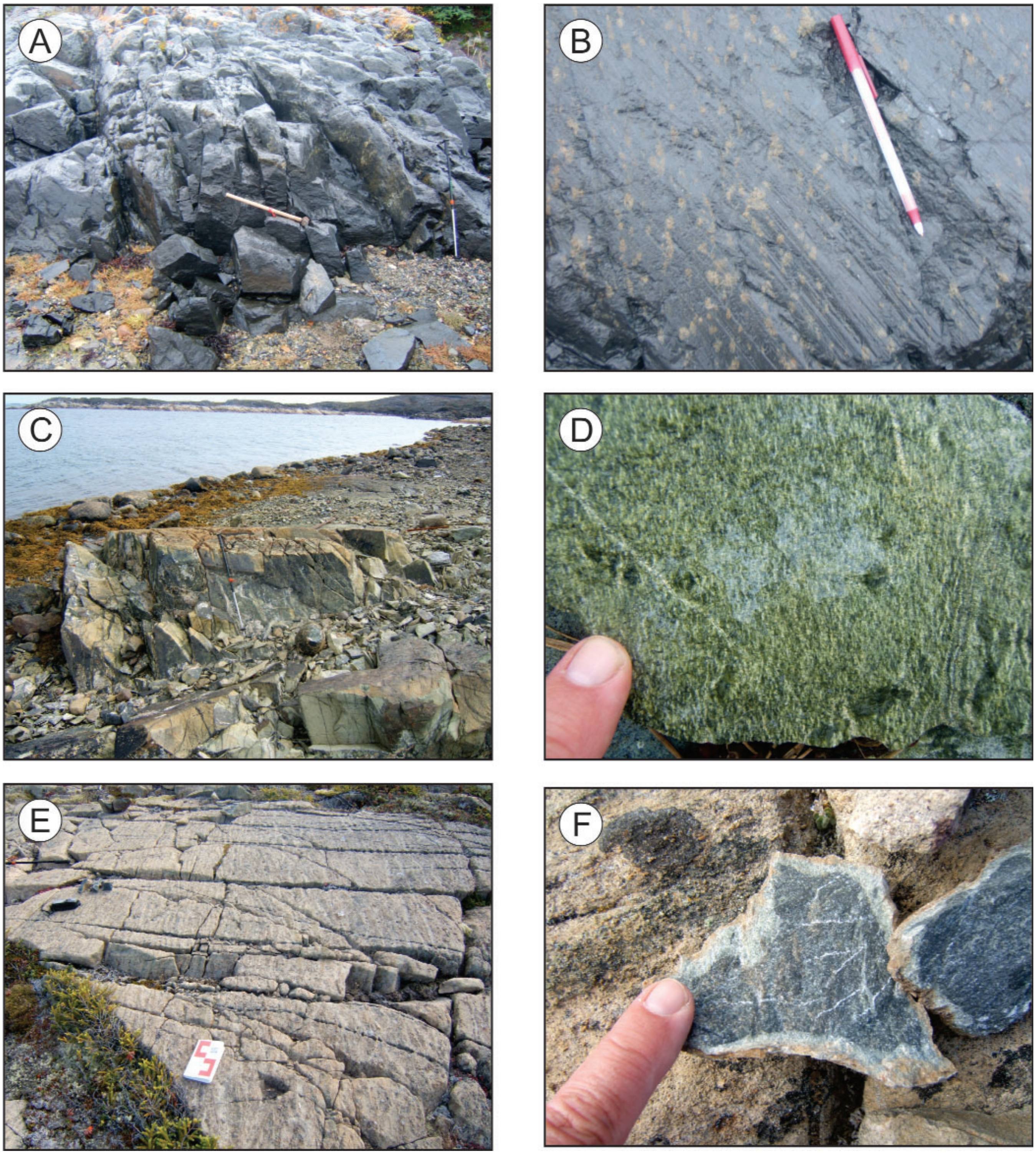

Plate 5. *Serpentinites from the Soapstone Cove Zone. A) Typical serpentinite outcrop on the coast, showing dark colour and orthogonal jointing; B) Texture of serpentinite in 'A', showing brown flecks of relict orthopyroxene and prominent glacial striae; C) Outcrop of bright-green-weathering serpentinite on the beach, with loose material largely removed by local carvers; D) Bright-green-weathering serpentinite variety exposed on the coast at Soapstone Cove – close-up of surface texture and colour; E) Part of the 'Green Site' outcrop of soft serpentinite, showing the pale-brown weathering and prominent jointing; F) Fresh surface of serpentinite from the Green Site, showing inner green weathering and outer brown weathering. Scratches on sample were made with a copper wire.*

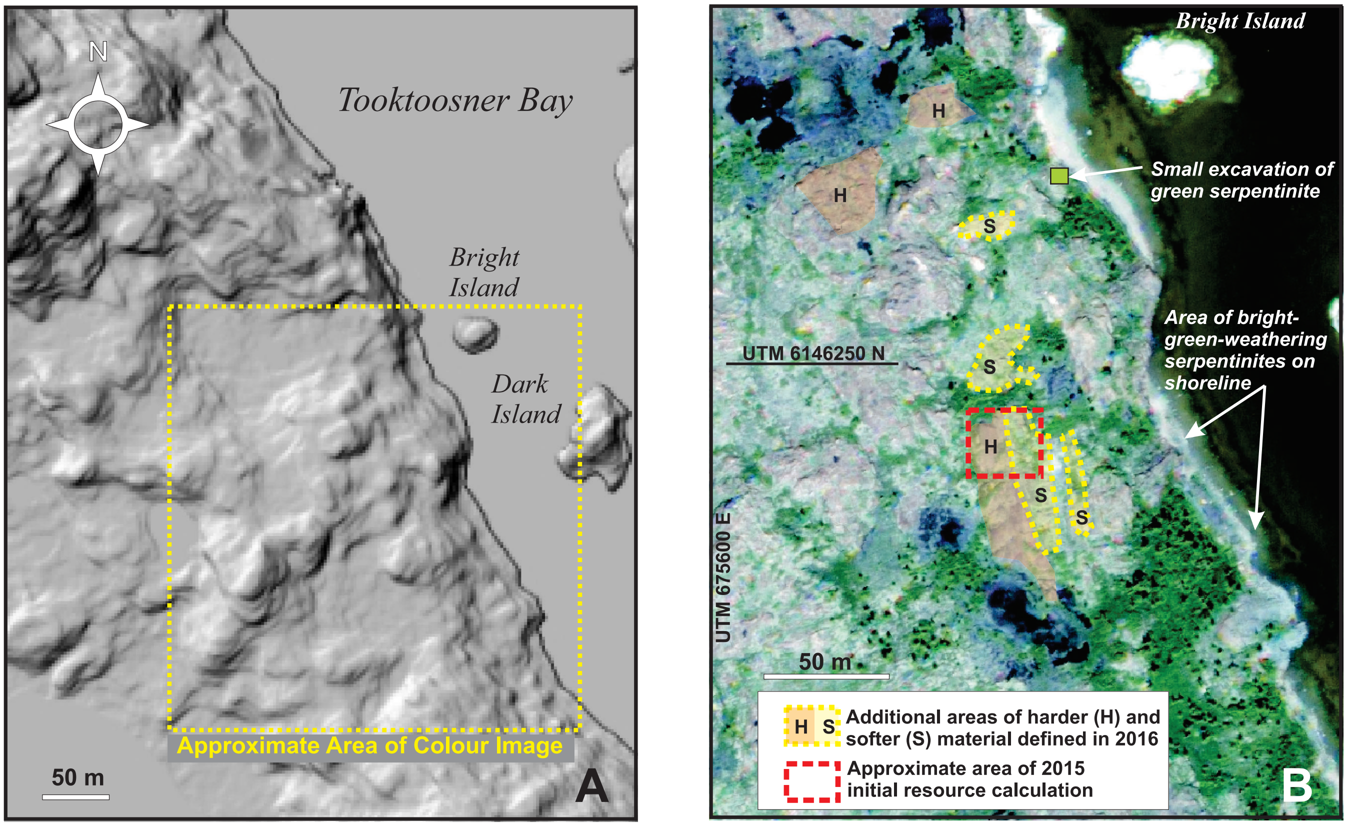

Figure 5. *A) Shaded relief map of the area around the principal site of interest ('Green Site') derived from satellite imagery; B) Detailed satellite image of the area around the Green Site, showing details of local geology, boundaries of initial resource calculation (Kerr, 2015) and additional areas of interest defined by Squires* et al. *(2016). Satellite imagery by Digital Globe; provided by the Department of Geography at Memorial University.*

ural' quarry site, formed from a valley-like indentation in the hills floored by a raised terrace about 5 m above sea level (Plate 7). This valley-like feature and its surrounding cliffs may represent part of a raised postglacial shoreline. The site is bounded to the west by Maggo gneiss, and this contact is interpreted to dip steeply northwest, based on foliation attitudes.

The rocks at the Valley Site are dark-grey serpentinites that are easily scratched with a knife, and are, locally, softer than copper wire, but they are generally harder and more variable in hardness than those from the Green Site and surrounding areas. There are very few crosscutting granite veins, and the outcrops have a well-developed orthogonal joint pattern. More detailed investigation and sampling confirmed that there is considerable variation in hardness and suggested that most areas are harder than copper wire (*i.e.*, >4 on Moh's scale), but the site also includes softer materials that were rated as 'good' by local carvers (Squires *et al.*, 2016). The estimated resource at the Valley Site is large, amounting to almost 14 000 m^3 using a horizontal datum of 5 m, and 20 000 m^3 if a horizontal datum of 3 m is adopted. The total available tonnage of some 60 000 tonnes is twice as large as that currently identified at the Green Site (*see* above), so it would certainly qualify as a potential regional supplier. However, it is not yet clear how much of the material here is suitable for carving. More work is required to better define the characteristics of the material and map hardness variations, as there may be localized zones of high potential within this extensive area.

Northern Zone

These are the closest outcrops of altered ultramafic rocks to Hopedale. The site of most interest is a rounded headland adjacent to a sheltered cove, located about 500 m north of the Valley Site (Figure 3). There is no known history of stone extraction but some areas of possible small-scale excavation were noted in part of the outcrop. The site is known as the 'Headland Site', and is illustrated in Plate 8. The dark-grey to black serpentinite shows variable hardness, with variable preservation of original textures. Several outcrop surfaces show a well-developed glacial polish, which is an encouraging sign for general carving potential. A

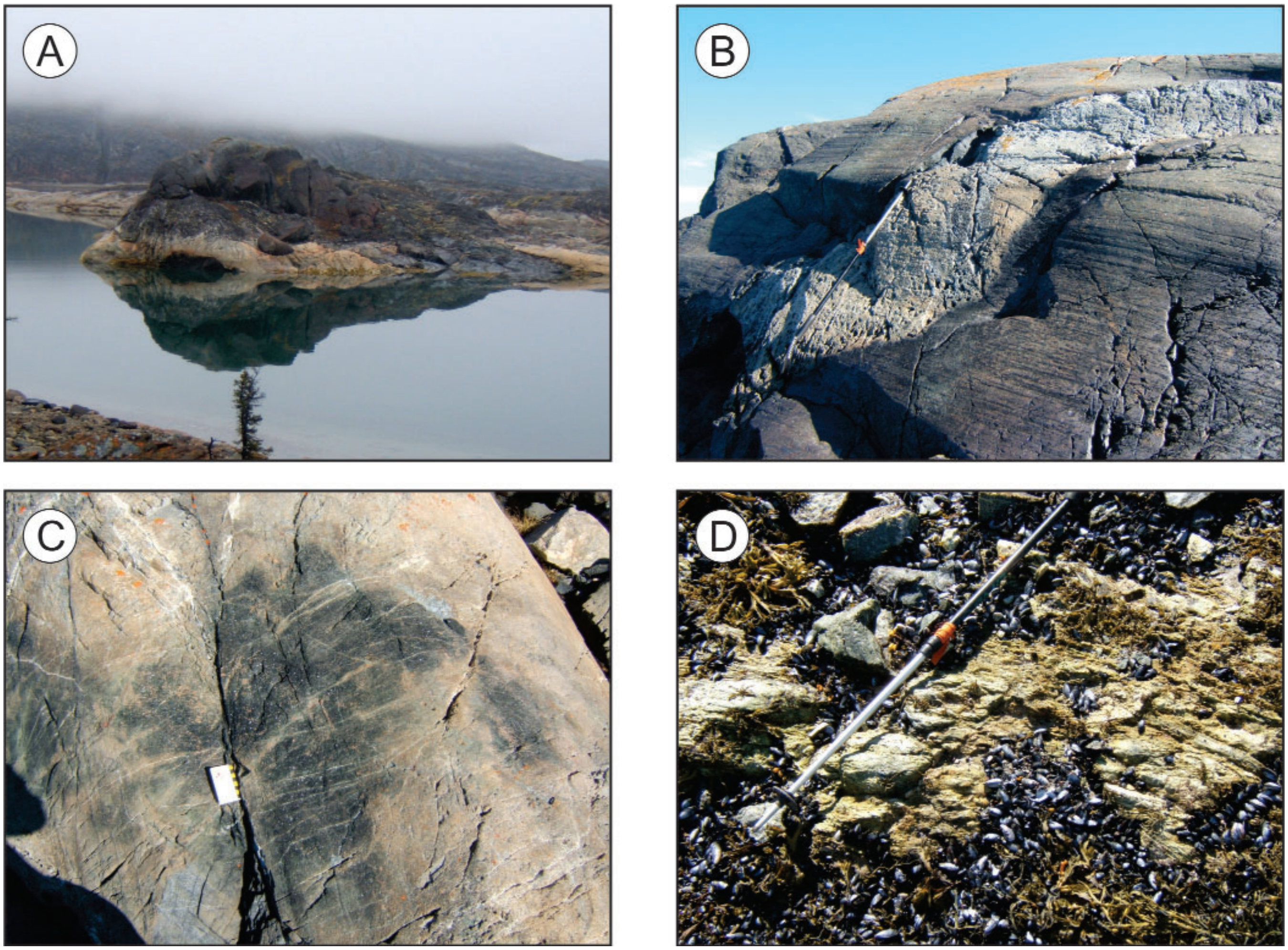

Plate 6. *Serpentinites from the Dark Island Zone. A) View of Dark Island; the pink band near the shore is a granite, but most of the island consists of ultramafic rocks; B) Vein-like zone of serpentinization cutting less altered ultramafic rocks, with amphibole-rich zones at its margins; C) Pale-brown to beige-weathering serpentinite, showing the interior dark colour where the outer rind has been eroded; D) Pale-green-weathering schistose serpentinite, closely similar to the green-weathering material that has been exploited from the Soapstone Cove shoreline.*

resource calculation using a horizontal datum of 2 m suggests a total volume approaching 18 000 m^3, or 54 000 tonnes. As in the case of the Valley Site, much more work is needed to characterize this material and evaluate its suitability for carving. Squires *et al.* (2016) suggested that most of the material at the site has a hardness greater than copper wire (>4 on Moh's scale). Test samples extracted in 2016 proved to be generally harder than material from the Green Site, but one sample from the Headland Site was rated as 'good' by local carvers.

Gully Zone

Serpentinized ultramafic rocks were identified in this inland location by Kerr (2015), and are associated with quartz–diopside-rich rocks of Unit 3. The serpentinite is pale grey on fresh surfaces, and variable in its hardness, but is locally softer than copper wire. No resource estimates were attempted here, because the site was visited only once, and its characteristics are not well known.

PETROLOGY AND GEOCHEMISTRY: PRELIMINARY RESULTS

Preliminary petrographic examination of selected samples was completed via a student project at Mount Royal University (C. Toner, unpublished data, 2017) and related work is in progress. Results confirm that the ultramafic rocks vary in texture and mineralogy, reflecting the intensity of serpentinization. At one extreme are relatively fresh, medium- to coarse-grained granular rocks that retain some primary igneous textures; these consist largely of orthopy-

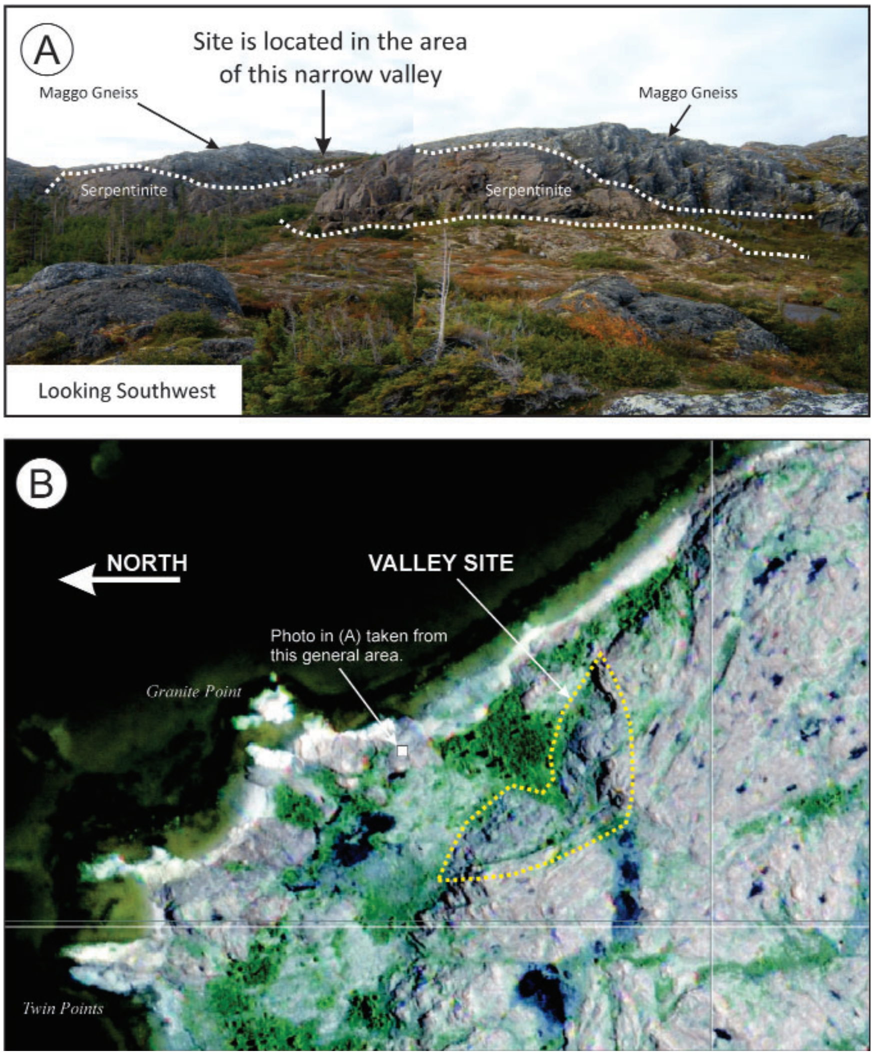

Plate 7. *Valley Site location, Twin Points Zone. A) Composite panoramic view of the Valley Site, taken from the coast near Granite Point (see B). The Valley Site occupies an indentation in the hills, which is probably part of an ancient raised shoreline; B) High-resolution satellite image of the Twin Points Zone and nearby areas, with north to left of photo. The Valley Site is visible due to the contrasting weathering colours of serpentinite and Maggo gneiss.*

roxene and olivine (*i.e.*, they are harzburgites), as previously noted by Ermanovics (1993). At the other extreme are pervasively altered rocks that consist largely of fine-grained serpentine and chlorite, but still retain a few vestiges of original igneous minerals. Strongly serpentinized samples, such as those from the Green Site, typically contain some small relict grains of orthopyroxene or more rarely olivine. Such grains are small and isolated, and thus easily abraded during carving and polishing, so they do not significantly affect the physical properties of the material. Most of the ultramafic rocks fall somewhere between these two end-members. Serpentinization preferentially affects areas rich in olivine, and this mineral is almost completely replaced by serpentine minerals in the softer rocks; originally larger orthopyroxene crystals are also partly transformed to serpentine, but retain scattered remnants of less altered material, which form the brownish blotches seen on weathered surfaces. Amphibole occurs in some fresher samples, as does mica (probably phlogopite) but it is not clear if these are original igneous minerals, or remnants of earlier alteration assemblages. Samples from the metasedimentary (?) rocks of Unit 3 contain abundant quartz and a green, granular pyroxene (probably diopside). They contain little or no carbonate minerals, and no garnet was identified, even though this unit is suspected to be the host for the 'uvarovite garnet' described by Brinex (Grimley, 1959). The exact location of the uvarovite-bearing outcrop remains a mystery, unless it is a case of mistaken identity involving imposter diopside.

Geochemical data appear to track the intensity of serpentinization as variations in loss-on-ignition (LOI) determinations that record the abundance of volatile constituents such as H_2O and CO_2. The most pervasively altered rocks, such as the green-weathering serpentinites of the Soapstone Cove Zone, typically have 12 to 14 wt. % LOI, whereas the least altered ultramafic rocks typically have less than 4% LOI, and most other samples fall somewhere in between these extremes. Strongly serpentinized rocks also typically have higher MgO contents and lower CaO and FeO contents than their less altered counterparts, but this does not necessarily indicate chemical changes related to the alteration. It is equally possible that the original rock types were richer in olivine and were thus more susceptible to complete transformation. Most of the ultramafic rocks contain elevated Cr (1200 to 4400 ppm) but the pervasively altered varieties generally contain less Cr and more Ni than the fresher rocks, which may also reflect some original compositional differences. Patterns for trace elements have not been investigated in detail, but there are no obvious trace-element contrasts that correlate with the intensity of serpentinization, as indicated by LOI.

Plate 8. *Serpentinites from the Northern Zone. A) View of the two rounded headlands that make up the Headland serpentinite site, located close to Hopedale; B) Serpentinite outcrop at the Headland Site, showing dark colour and well-polished outcrop surfaces; C) Well-developed glacial striae on polished serpentinite outcrop at the Headland Site; D) Weathered surface of Headland Site serpentinite, showing brown patches of relict orthopyroxene, typical of the outcrop.*

Interestingly, two samples of quartz- and diopside-rich metasedimentary (?) rocks also show elevated Cr (2900 and 3600 ppm); these values are similar to those reported for many of the ultramafic rocks.

DISCUSSION AND CONCLUSIONS

The area covered by this investigation is truly small, but it is also truly a microcosm of the typical complexity of the Archean Hopedale Block, and it reveals many interesting scientific problems. These include the nature and age of the Tooktoosner ultramafic suite, its relationship to the Weekes amphibolite and related rocks, and its original relationship to quartz- and diopside-rich metasedimentary (?) rocks with which it seems to be spatially related. Other problems of interest include the controls on the development of serpentinized zones, which may be compositional (*i.e.*, they could develop from rock types that were originally more olivine-rich) or structural (*i.e.*, they could develop along sheared contacts between ultramafic units and older rocks), or could involve a combination of these controls. These questions can only be answered through additional detailed field work, and more systematic petrological and geochemical investigations, which are outside the scope of this report.

The pragmatic short-term objective of this investigation was to define more extensive zones of soft serpentinite that could provide sources of carving stone for Nunatsiavut artists. This was achieved with recognition of a zone extending for over 200 m along strike, located a short distance from the shoreline of Soapstone Cove, but at an elevation that would permit extraction of stone. The material at the 'Green Site' appears to be closely similar to the bright-green-weathering soft serpentinite that occurs on the local shoreline, which has long been exploited from loose blocks and fractured outcrops. This suggests that the stone is well suited to the needs of local artists, and limited test carving supports this conclusion. The initial resource estimates of up to 5500 m^3 in 2015 were expanded to around 30 000 m^3 in 2016, although a portion of this (around 2500 m^3) is thought to be a harder pyroxene-rich variety that may not prove as amenable for carving. Regardless of such complications, the Green Site represents a significant potential resource of potential carving stone that falls into the 'regional supplier' category as defined by similar surveys in Nunavut.

Four other zones of serpentinized ultramafic rocks that may have potential for carving stone were also identified in the Tooktoosner Bay area, and two of these (the 'Valley Site' and the 'Headland Site') may also fall within the 'regional supplier' category. However, the characteristics of the stone in these areas are not as well known as those of the Green Site, and initial indications are that the intensity of serpentinization is more variable, and that there may be more significant variations in hardness. These areas may still have potential for carving-stone extraction, but the material may be less amenable to hand-carving methods, and softer material may only be present on a more local scale.

Further geological and assessment work is required in all these areas to establish the feasibility of extracting stone, and how best this might be accomplished. In the case of the Green Site, systematic sampling and testing by carvers is needed to refine the resource estimates for the highest quality materials. For the other sites, additional prospecting, sampling and test carving is needed to better understand the nature of the stone and its variability, notably with respect to hardness, and to look for subzones of more intensely altered softer material within the larger resource envelopes.

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